A NEW SPECIES OF *CALAMOECIA* (COPEPODA: CALANOIDA) FROM ARID AUSTRALIA, WITH COMMENTS ON THE CALANOID COPEPODS OF THE PAROO, NORTHWESTERN MURRAY-DARLING BASIN

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Calamoecia baylyi sp.nov. is described from claypans in the Paroo catchment in southwestern Qld and northwestern NSW. It also occurs in WA where it was previously known as the Cue form of *C. lucasi*. Ten species of calanoid copepod occur in the Paroo with *Boeckella triarticulata, C. canberra* and *C. lucasi* common, *B. fluvialis and C. zeidleri* present and *B. robusta robusta, B. timmsi, C. baylyi, Diaptomus lumholtzi* and *Gladioferens spinosus* uncommon. Co-occurrences are common, especially in claypans and riverine waterholes. ❒ *New species, Calamoecia, Calanoid copepods, environmental ecology, biogeography.*

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Calamoecia Brady contains 16 species (Bayly, 1992, 1998; Halse & McRae, 2001). Two of the most recent additions, *C. zeidleri* Bayly and *C. halsei* Bayly live in waters in remote parts of arid Australia. Also occupying some of these waters is a form similar to *C. lucasi* Brady but different enough to be recognised as the Cue form (Bayly, 1984). It has been reported from Cue (Bayly, 1984), near Port Hedland (Timms & Morton, 1988), and the Gascoyne-Murchison (Bayly, 1998), all in NW WA. Although Bayly (1998) thought this western form of *C. lucasi* was a new species, he was reticient to proceed partly because it is allopatric with *C. lucasi s. s.* (I.A.E. Bayly, pers. comm.). *C. lucasi s.s.* is widespread in eastern and central Australia (Maly & Bayly, 1991), but records of *C. lucasi* in WA in Maly & Bayly (1991) and in Maly et al. (1997) refer to its western form (alias Cue form) (Maly & Bayly, 1991, and S. Halse, pers. comm.). However *C. lucasi s.s.* occurs at Lake Gregory, S Kimberley (Halse et al., 1998) and another variant of *C. lucasi*, the 'Lake Grace form' lives near Lake Grace in SW WA.

Discovery of populations similar to the Cue form in the Paroo, NW NSW and SW Qld, and sympatric with *C. lucasi s.s.* confirmed that the Cue form is a separate species. Not only are there many differences between it and *C. lucasi s.s.*, but the Cue form has maintained its distinctiveness despite chances for interbreeding.

The Paroo area contains 9 other calanoid copepods including many inland forms for which few ecological data are available. Ecological and biogeographic studies on Australian calanoid copepods (Bayly, 1996; Maly, 1984; Maly & Bayly, 1991; Maly & Maly, 1997; Maly et al., 1997; Timms & Morton, 1988; Walsh & Tyler, 1998) have not included data from the eastern arid zone.

The aims of this paper are to describe the Cue form of *Calamoecia lucasi s.l.* and to comment on ecological biogeography of calanoid copepods in the Paroo catchment of the NW Murray-Darling Basin.

METHODS

Specimens were measured under a Wild M3C stereomicroscope fitted with an eyepiece micrometer, stained with Chorazol Black, and dissected with tungsten needles in DePeX mountant on a microslide under the same microscope. Appendages were studied and drawn using a Olympus BHA microscope fitted with Olympus drawing attachment. Terminology and abbreviations used in describing the appendages follow Bayly (1992).

Ecological data on the copepods of the Paroo are gleaned from my monitoring studies of 100+ wetland sites over 13 years (Timms 1993, 1997a, 1997b, 1998; unpubl. data). The area covered ranges from Currawinya National Park in the N (centred on 144°25'E, 28°50'S) to Lake Peery in the Overflow lakes area (143°37'E, 30°45'S) and encompassing about two-thirds of the Paroo's catchment of 73, 600km^2.

SYSTEMATICS

Class CRUSTACEA
Order COPEPODA
Family CENTROPAGIDAE Giesbrecht
Calamoecia Brady

Calamoecia baylyi sp. nov.
(Figs 1, 2)

Calamoecia lucasi Brady; Bayly, 1984 (in part, the Cue population, fig. 4A-D).

ETYMOLOGY. In honour of Dr Ian A.E. Bayly, to whom so much is owed on the taxonomy and ecology of centropagid copepods.

MATERIAL. HOLOTYPE ♂ QMW25483, length 0.77mm prosome, 1.19mm total, ALLOTYPE ♀ QM W25484, length 1.10mm prosome, 1.52mm total, both mounted on microslides in DePeX., PARATYPES 30 ♂s, 20 ♀s QMW25485, Queensland Museum. Collected by the author on 17 May, 1996. OTHER MATERIAL. 30 ♂s, 15 ♀s QM W25487, Turkey Pan, 29°33'S, 144°49'E, Bloodwood Station, 130km NW of Bourke, NSW,collected by the author, 19 May, 1998; 5 ♂s, 3 ♀s, Melaleuca Pan, 29°33'S, 144°48'E, Bloodwood Station, NSW, collected by author 19 May 1998; a claypan near S end of Lake Wyara, Currawinya National Park, 28°48'S, 144°15'E, Qld, collected by author 14 May, 1996; dissected ♂ WAM C24994 and vial of 10 ♂s and 10 ♀s WAM C24996 from an unnamed claypan, 24°47'35"S, 114°09'14"E (CB 58e of Halse et al., 2000), collected S.A. Halse 25 July 1995; dissected ♀ WAM C24995 from Tirigie Claypan, 24°38'34"S, 113°59'29"E, collected by S. Halse 17 August, 1994.

TYPE LOCALITY. A claypan 1.5km NE of Coomburra Waterhole, Currawinya National Park, 28°47'E, 144°22'E, SW Queensland.

DESCRIPTION. *Male*. On first legs, outer edge spines on exopodite promixal segment (Re1) and distal segment (Re3) with abnormally large secondary spinules (same in females [Fig. 1A]). On fifth leg (Fig. 1B,C) distal basidopodite segment (B2) with a distinct space between insertion of exopodite and endopodite, which in the right limb is wider and a little indented. Proximal segment of right exopodite (Re1) somewhat cuboidal with a spine on its outer distal corner and a small rounded protrusion on its inner distal corner. Middle distal segment (Re2) with a prominent rounded projection midway on its inner surface. Claw (Re3) strongly bent about one-quarter way along its length, and lacking an inner spine. Right endopodite (Ri) 3-segmented, proximal (Ri1) and middle segment (Ri2) round-oval shaped, but distal segment (Ri3) more elongated and bearing 2 long setae subterminally. Left exopod (Re)1-segmented with a small spine two-thirds along outer margin and tip expanded into rounded spade-like structure with denticles on and towards its margin. Base of this structure with short spine on a protuberance on the inner side and longer spine next to it. Left endopodite (Ri)1-segmented, a little longer than the first 2 segments of the right exopodite (i.e. exopodite without its claw), with almost parallel sides. This segment with 5 spines (2 terminal, 3 subterminal) decreasing almost uniformally in length from the inner spine to outermost one.

Female. On first legs (Fig. 1A), spine on outer edge of proximal segment (Re1) and 2 spines on outer edge of distal segment (Re3) of exopodite with abnormally large secondary spinules (as in ♂). These outer spines absent on exopods of legs 2-4. On fifth leg (Fig. 1D), proximal exopodite segment (Re1) with an outer spine with secondary spinules. Middle exopodite segment (Re2) also with such a spine and a large curved slender outgrowth on its distal inner corner. This outgrowth with 2 rows of spinules. Distal exopodite segment (Re3) with 5 or 6 spines, outermost with secondary spinules, next inner one longest but still a little shorter than the segment. Curved outgrowth on Re2 subequal to Re3 plus its spines. Endopodite (Ri) 1-segmented, with 7 or 8 long setae (4 or 5 on inner side, 1 terminal, and 2 on outer edge.). Prosome terminating in elongated lobes on either side of prosome-urosome junction (Fig. 1E,F). Urosome (Fig. 1E,F) with genital segment about 1.5 × as long as wide. Genital operculum with a distinct nipple and on a large mound. Left side of genital segment with a bulge almost halfway along its length, but no indication of an associated furrow.

REMARKS. *Variation between populations*. Specimens from the Carnarvon region of WA are slightly different from the type material in a number of features. On the ♂ fifth leg, the spine of the outer distal corner of the first exopodite segment (Re1) is much longer (Fig. 2B). The claw of the right exopodite (Re3) is markedly bent further along its length than in type material (ca one-third to halfway along its length). The right endopodite is curved inwards and the first and second segment (Ri1, Ri2) even more bulbous so that especially the second segment presents a semicircular outer edge (Fig 2B). In the ♀ the most noticeable difference is on the third segment of the exopodite (Re3) where spines (6 instead of 5) are longer than in the type material, so that they exceed the length of the segment and of the curved inner process of the second segment (Re2) (Fig. 2A). Bayly (1998) thought different material he examined from the Carnarvon region 'agreed exactly with the Cue population', i.e. was the form now known as *C. baylyi*.

The Cue population of *C. lucasi s.l.* studied by Bayly (1984) is almost identical to the type material from the Paroo. Like the Carnarvon population the second segment of the right endopodite (Ri2) in ♂ is enlarged and with a semicircular outer edge, and in ♀ the proportions and lengths of the spines on the third exopodite segment are the same.(Fig.2C; Bayly, 1984, fig. 4). The Cue population is similar to the Paroo type material in other features, including the short spine at the outer distal corner of the first right exopodite segment (Re1) and the marked bend in the right exopod claw (Re3) being about a quarter to a third along its length. Both these western populations of *C. lucasi s.l.* are considered as belonging to *C. baylyi*.

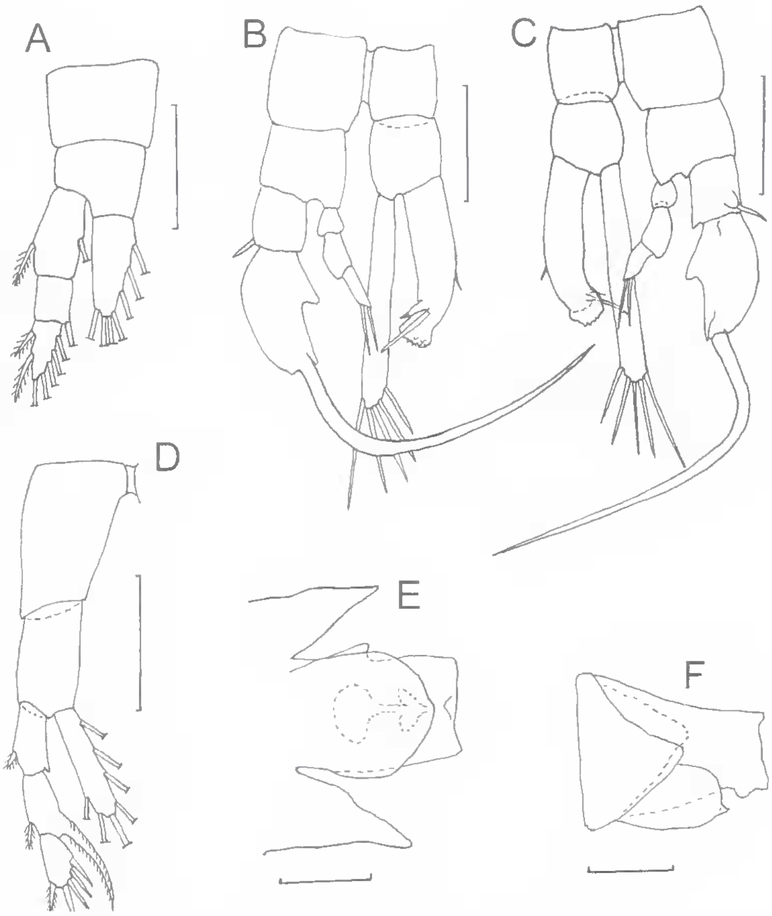

FIG. 1. *Calamoecia baylyi* sp. nov.; A, ♀ first leg; B & C, anterior and posterior aspects, respectively, of ♂ fifth legs; D, ♀ fifth leg; E, ventral aspect of ♀ genital segment with lobes of last prosomal segment; F, left lateral aspect of ♀ genital segment with lobes of last prosomal segment. B and C from holotype, A, D, E, F from allotype. Scale bars = 0.1mm.

The Lake Grace population of *C. lucasi s.l.* studied by Bayly (1984) exhibits most of the features of *C. baylyi* including most of the minor modifications seen in the Carnarvon and Cue material. It has however some curious features unique to it, including an outgrowth on the inner distal corner of the proximal segment of the right exopodite (Re1). This is much more prominent than the usual small rounded protrusion in typical *C. baylyi*, but not as long as in *C. elongata*, the only other species with an outgrowth in this position. Also unique to this population is the variable setation on the distal segment of the right endopodite (Ri3) so that generally the 2 setae are of very unequal lengths and usually much reduced. In addition some of the features typical of *C. baylyi* are either not as well developed (e.g. the projection midway along the inner surface of the middle right exopodite (Re2) is hardly developed) (Fig. 2D), or more developed (e.g. the outgrowth on the left side of the genital segment is more pronounced) (Bayly, 1984, fig. 5E,F). This Lake Grace material should be considered as *C. baylyi*, though a little more abberant than other western populations.

For 5 populations of *C. baylyi*, prosomal lengths are a little less than 1mm, with ♂ lengths ca 10% less than ♀ (Table 1).

Differential Diagnosis. C. baylyi is easily recognisable by the rounded projection on the middle inner surface of the second right exopodite segment (Re2) of the male (Fig. 1B,C). The only other species with a remotely similar structure is *C. australica*, in which the projection

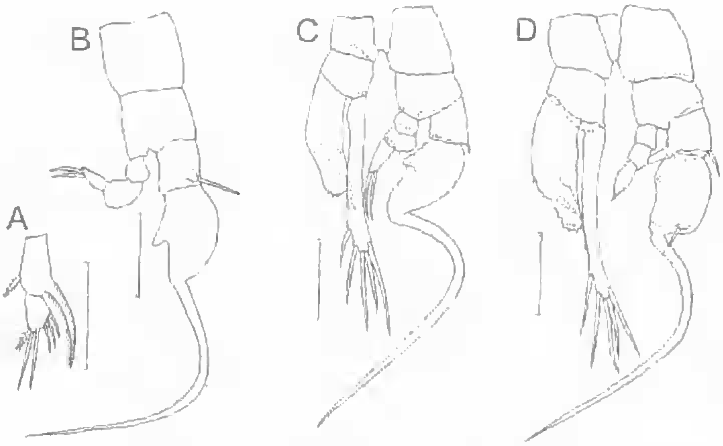

FIG. 2. *Calamoecia baylyi* sp. nov. from WA; A, second and third segment of exopodite of ♀ fifth leg, specimen from Carnarvon basin (see Material for details); B, posterior aspects of ♂ right fifth leg, specimen from Carnarvon basin; C, posterior aspect of ♂ fifth legs, Cue population (after Bayly, 1984, fig. 4A); D, posterior aspect of ♂ fifth legs, Lake Grace population (after Bayly, 1984, fig.5A). Scale bars = 0.1mm.

is about a third along the inner edge and moreover sharp pointed.

Other notable features are variously shared with a limited range of other species. These include:

1) Outer edges of the exopods of the first pair of legs in both sexes have 3 spines each with a few large stout secondary spinules (Fig. 1A). Of other *Calamoecia* species examined for these spines, *C. halsei* has them and significantly *C. lucasi s.s.* does not (Bayly, 1998).

2) The claw of the right exopodite of the ♂ fifth leg (Re3), lacks an inner spine (Fig. 1B,C) as in *C. australica*, *C. canberra*, *C. halsei* and *C. zeidleri* (Bayly, 1998). *C. lucasi s.s.* also lacks this spine but all other species have it (Bayly, 1992).

3) The left endopodite of the ♂ fifth leg (Ri1) is 1-segmented, very elongated, exceeding the length of the left exopod and bears 5 terminal and subterminal spines. This feature is shared with the same 4 species listed above, but usually not with *C. lucasi s.s.*, which although of similar construction, has 2-5, usually 4 terminal/subterminal spines, (Bayly, 1961,1992, 1998).

4) The left exopodite of the ♂ fifth leg is 1-segmented and with a spade-like terminal protrusion bearing denticles (Fig. 1B,C). In a broad sense, this feature is shared only by *C. ampulla* and *C. lucasi s.s.*, but the latter has no terminal denticles. In addition, *C. lucasi* lacks an inner subterminal spine that is present in *C. baylyi* and overall the length of the left exopodite is shorter relative to the left endopodite (a little greater than half in *C. lucasi s.s. cf* three-quarters in *C. baylyi*).

5) On the ♀ fifth leg, the curved outgrowth on the inner distal corner of the middle exopodite segment (Re2) is relatively long in *C. baylyi* reaching about to the end of the distal exopodite segment plus its spines (Fig. 1D). In many other species, including *C. lucasi* s.s., this outgrowth terminates well short of the distal segment plus its spines (Bayly, 1961). Only *C. halsei* exhibits a similar condition (Bayly, 1998).

6) Again on the ♀ fifth legs, some of the 5 or 6 spines of the distal exopod segment (Re3) are only a little longer than the length of the segment in *C. baylyi* (Fig. 1D), as for *C. halsei* (5 spines) and *C. salina* also (but *C. salina* has only 2 terminal spines instead of 6). By contrast in most other species of *Calamoecia*, including *C. lucasi*, the spines are more than twice the length of the segment (Bayly, 1961) and significantly in *C. lucasi s.s.* there are only 5 spines, though some species have 6 (e.g. *C. trifida*). Only *C. zeidleri* has shorter terminal spines (which number 5) (Bayly, 1984).

In the dichotomous key provided by Bayly (1992), *C. baylyi* would key out through couplets 1,2 8,9 and 11 to *C. lucasi*, but as pointed out above is easily distinguished from this species. Also, as shown by Bayly (1984) the Cue form of

TABLE 1. Prosomal lengths in mm of 10 ♂s and 10 ♀s from 5 populations of *C. baylyi*. * Only 6 ♂s and 4 ♀s measured.

Population	Mean ♂ length	Range of ♂ lengths	Mean ♀ length	Range of ♀ lengths	Source of data
CNP, Paroo	0.87	0.78 – 0.92	0.94	0.91 – 0.98	Original
Bloodwood, Paroo	0.89	0.85 – 0.94	0.96	0.92 – 1.01	Original
Carnarvon, WA*	0.89	0.86 – 0.90	0.98	0.97 – 1.00	Original
Cue, WA	0.86		0.96		Bayly, 1984
L. Grace, WA	0.93		1.00		Bayly, 1984

C. lucasi, i.e. now *C. baylyi*, is markedly larger than *C. lucasi s.s.*. The same applies in the Paroo where the 2 species are sympatric. In Lake Numalla (Currawinya National Park) which has a perennial population of *C. lucasi s.s.* a mean female prosomal length of 0.68mm has been recorded from measurement of 30 individuals (author unpublished) compared to 0.94mm (Table 1) of *C. baylyi* in a nearby claypan.

Ecology. *C. baylyi* lives in turbid temporary freshwaters, particularly in very turbid claypans (as in six sites in the Carnarvon region of WA (Halse et al., 2000), and the four present sites in the Paroo). In the Paroo it occurs in these pans soon after filling, passes through one generation and disappears after a few weeks (Fig. 3).

In the Carnarvon region it co-occurs with *C. canberra* or *B. triarticulata*, but not with the similarly sized *C. halsei* (female prosome length 0.81 - 1.00mm (Bayly, 1998)) which also lives in turbid claypans (S. Halse, pers. com.). Further work is needed to determine whether *C. baylyi* and *C halsei* are competitors or have slightly different habitat preferences. The collection from near Lake Grace also had *B. opaqua* and *B. robusta maxima* (Bayly, 1984) while Halse's collections from the same locality contained just *B. robusta maxima* as well as *C. baylyi* (S.A. Halse, pers. comm.) In the Paroo other co-occurring copepods include *B. robusta robusta*, *B. triarticulata*, *B. timmsi*, *Calamoecia zeidleri* and *C. canberra*, with co-occurrences of up to 4 species common (Hancock & Timms, unpubl. data). In all of these co-occurrences *C. baylyi* is a medium sized *Calamoecia*, larger than *C. canberra*, but smaller than *C. zeidleri* and all the *Boeckella* species.

Distribution. *Calamoecia baylyi* occurs in the arid and semi-arid zone. In more detail, it is found widely in the western third of WA from Port Hedland in the north (Timms & Morton, 1988), through the Carnarvon basin (Maly et al., 1997), to Cue (Bayly, 1984) and near Lake Grace in the southwest (Bayly, 1984). It has not been detected in eastern WA, possibly through lack of habitat or collecting effort, nor in northern SA and southern NT which has been searched extensively by W. Zeidler (in Bayly, 1984). In the Paroo in northwest NSW and southwest Qld, which has been intensively studied by the author for 13 years, it occurs very spasmodically in time and space.

COMMENTS ON OTHER CALANOID COPEPODS OF THE PAROO

Boeckella fluvialis lives mainly in waterholes associated with the Paroo R, and occasionally in lakes (e.g. L. Numalla) and pans fed by Paroo floodwater, all in the Currawinya National Park (Timms, 1997a). It also occurs in waterholes in the lower Paroo area. In all the waterholes it was most common following major flows, reaching c. 5-12% of the total crustacean zooplankton. In Lake Numalla it was restricted to the Coomburra Waterhole that receives Paroo floodwater and soon disappeared when the lake returned to normal. In the 2 pans reached by floodwater it persisted for only 10 days despite the pans having water for many weeks. Though *B. fluvialis* lives in ponds and lakes elsewhere in its distribution (Shiel, 1986; Timms, 1989; Maly et al., 1997) in the Paroo it prefers riverine habitats.

Boeckella robusta robusta lives only in turbid claypans, but there are <10 records in the Paroo probably because it is short-lived and is not common when present (typically 1-3% of total crustacean zooplankton) (Fig. 3). Its presence in NW NSW and SW Qld (QM W25486) adds considerably to the 3 localities in NSW and Tasmania listed in Bayly (1964). Bayly's (1964) contention that the Tasmanian record was possibly a misidentification is supported by the lack of any records in a state-wide study of Tasmanian calanoid copepods (Walsh & Tyler, 1998). Furthermore the Sydney locality recorded by Sars (1896) probably has now been urbanised. Therefore the known distribution of *B. robusta robusta* should be modified to include only W NSW and SW Qld.

Boeckella timmsi also inhabits turbid claypans and has been collected even fewer times than *B. robusta*. It is known from only 2 claypans — the type locality in CNP (Bayly, 1998) and Turkey Pan at Bloodwood Station (Hancock & Timms, unpubl. data). In the latter it matured earlier and its existence was briefer than other copepods (Fig. 3). It may be more common and widespread, but its short life and early appearance in pans soon after filling when they are difficult to access means it is rarely collected.

Boeckella triarticulata occurs in almost all wetlands sampled in the Paroo, making it common and widespread, as it is in much of Australia (Bayly & Williams, 1973; Maly, 1984; Shiel, 1986; Maly et al., 1997). It even lives in hyposaline lakes to c.18 g/L. Overall it is most common in sites that are partly turbid and without fish. Although not a characteristic species of turbid claypans (Timms & Boulton, unpubl. data), if they persist for many months, it maybe the only species present, and certainly the only species of *Boeckella* (Fig. 3) (Timms, in press).

C. canberra is also common and widespread throughout the Paroo, as might be expected from the distribution map given by Bayly (1984). It prefers turbid waters and is particularly common in claypans, even if they persist for months (Fig. 3). Though present in other lakes and river pools, it disappears in favour of *C. lucasi* when waters clear and does not survive should salinity increase above c. 5 g/L.

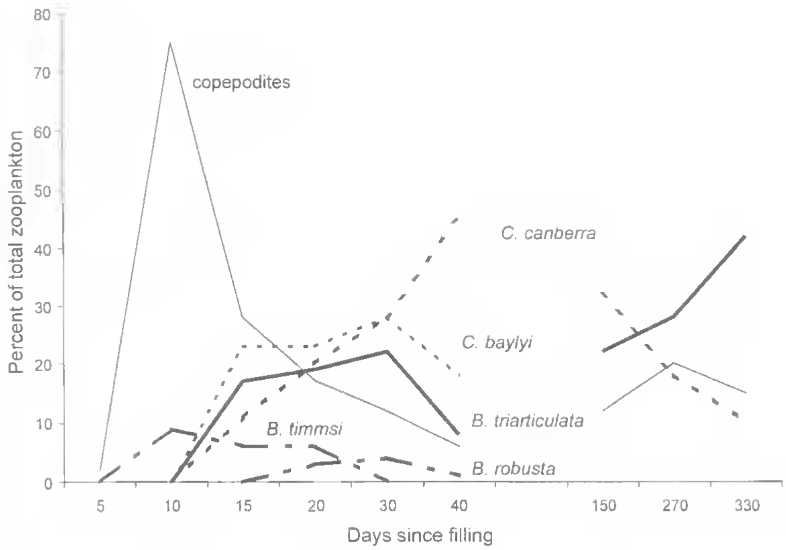

FIG. 3. Fluctuations in abundance of calanoid copepods in Turkey Pan, Bloodwood Station during a 'normal' fill in April-May 1998 and another prolonged fill in 2000 (mid to late stages only).

C. lucasi in the Paroo prefers larger lakes and riverine waterholes, often with less turbid water, e.g. L. Numalla, Corni Paroo Waterhole, L. Yantabadgee. Where fish are present it is usually the dominant calanoid copepod, as Maly & Maly (1997) have observed. It also occurs in smaller intermittent creek pools that persist for months, but not in turbid claypans, less persistent small pools or hyposaline lakes. These data concur with those on this species elsewhere in eastern and central Australia where it is widespread and common in larger permanent waterbodies (Bayly, 1978; Maly & Bayly, 1991).

C. zeidleri occurs throughout the Paroo, but only in turbid claypans, and then mainly in the early stages of filling. Its presence in the Paroo extends its distribution from NE SA (Bayly, 1984), and a collection from a claypan near Windorah, Qld (author, unpubl.) suggests it is distributed even further afield to include much of the central and eastern aridzone. Its presence in suitable intermittent waters, along with *C. baylyi*, *C. canberra* and occasionally *C. lucasi*, provide further exceptions to the observation that *Calamoecia* generally inhabits permanent waters (Bayly, 1978; Maly & Bayly, 1991).

Diaptomus lumholtzi occurs rarely in waterholes in the CNP, specifically Ourimperee and Killanbirdie Waterholes 4 times over 13 years of observation. All records pertain to summer floods and numbers were always <0.1% of total crustacean zooplankton. These occurrences are well S of its normal distribution (Timms & Morton, 1988) and must be due to some individuals being washed down from the north and surviving for a limited period. Halse et al. (2000) also have found this species somewhat S of its known distribution across N Australia (Timms & Morton, 1988).

Gladioferens spinosus is even rarer in the Paroo, with just one record in the summer of 1995-6 from Ourimperee Waterhole in CNP. This is the most northerly inland record for a species that normally occurs in some coastal freshwater lakes (Timms, 1973) and estuaries in SE Australia and N NZ (Maly & Bayly, 1991) and in floodplain rivers of the Murray-Darling Basin (Shiel, 1978; Shiel et al., 1982).

Co-occurrences are common among calanoids in the Paroo. The most numerous are between the larger *B. triarticulata* and the smaller *C. canberra* or *C. lucasi*, as noted elsewhere in inland Australia (e.g. Maly & Maly, 1997). Claypans regularly have multispecies complexes, with the relatively large *B. robusta*, then in decreasing order of size, *B. triarticulata*, occasionally *B. timmsi*, *C. ziedleri*, occasionally *C. baylyi*, and *C. canberri*. Bayly (1984) noted that *C. ziedleri* co-occurs with either or both of *B. triarticulata* and *C. canberra*; they are well separated by size. Riverine waterholes also occasionally have many co-occuring species which may include any combination *of B. triarticulata*, *D. lumholtzi*, *G. spinosus*, *B. fluvialis*, *C canberra* and *C lucasi*. In both habitats up to 5 species and often 3-4 species, have been seen coexisting. Some are <1.3 × other species in size and hence in possible competition (Hutchinson, 1951), but the situation is not persistent, as *B. timmsi* develops earlier than its congeners in pans, and other co-occurrences of similarly sized species (*B. triarticulata* /*D. lumholtzi* /*B. fluvialis* and *C canberra* /*C. lucasi*) are linked with temporary disturbance by flood waters.

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